Evolving Synchrophasor Data Network Architectures to Support Wide-Area Control & Protection

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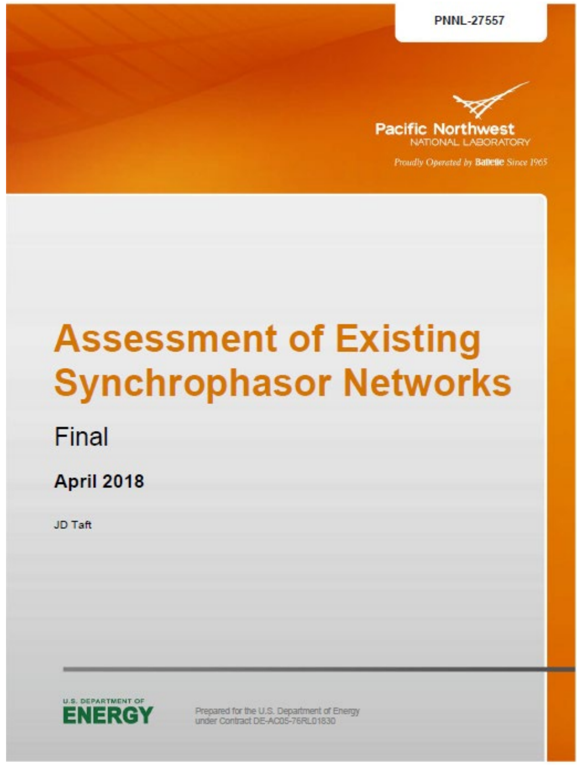
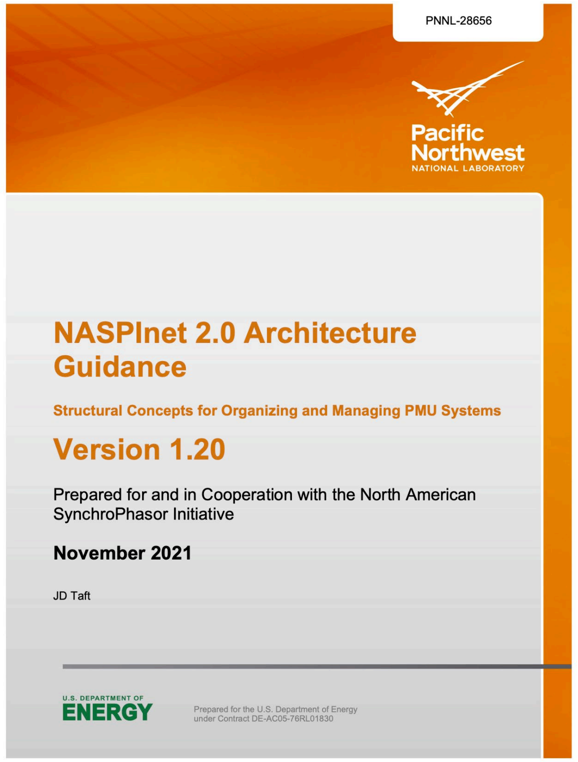
Background
NASPInet 2.0 Architecture Project

1. Assess the state of PMU networking
   - Review the existing NASPInet documents from 2007-2009
   - Analyze SGIG PMU projects with NASPInet implementations and other implementations
   - Identify lessons learned or learnable

2. Create a new guidance document (NASPInet 2.0)
   - Apply lessons from industry experience
   - Apply modern architecture principles & concepts
   - Improve flexibility, resilience, cybersecurity
   - Address for new technologies and emerging trends

3. Validate architecture guidance
   - Detailed reviews with industry experts
   - Architectural comparison studies



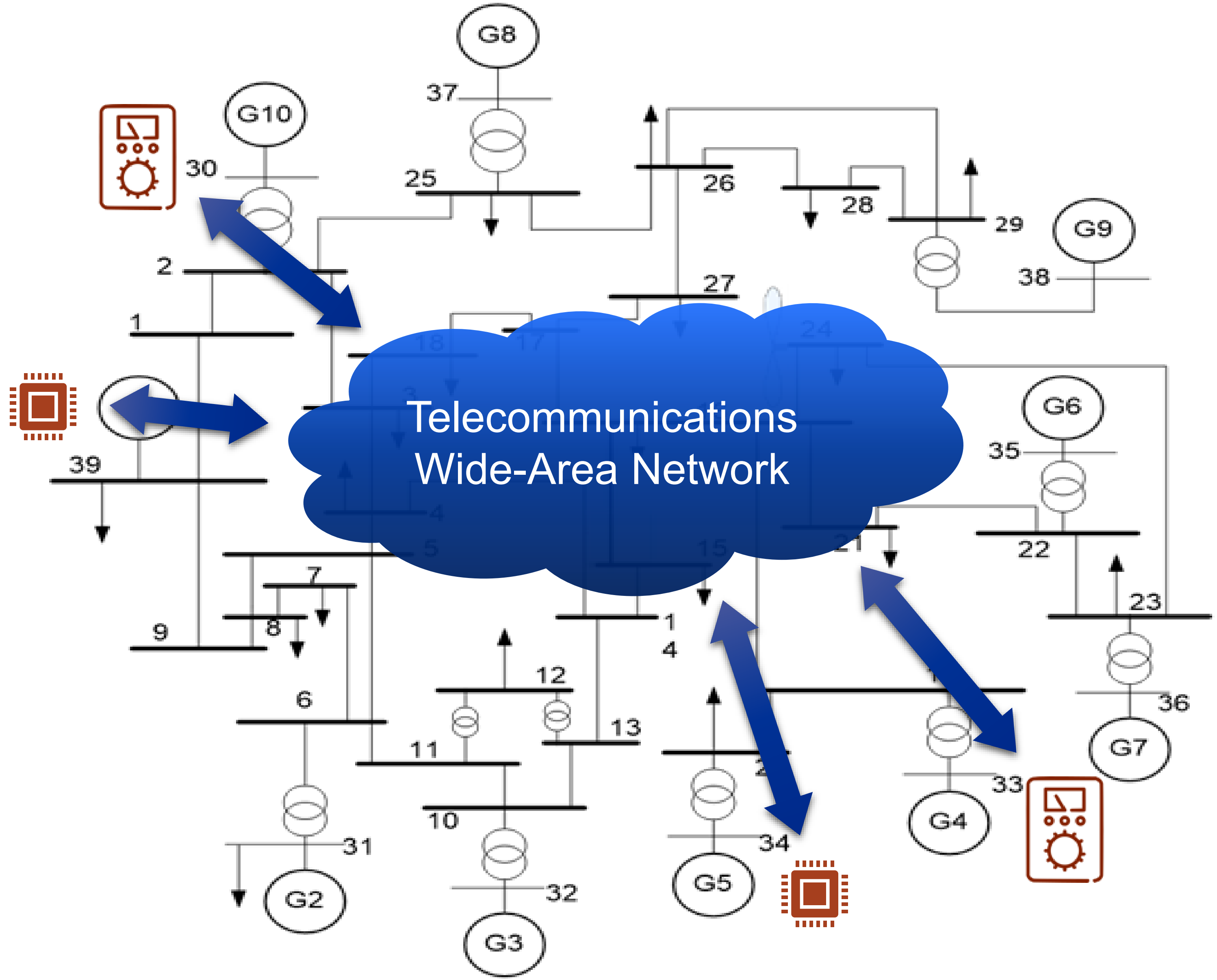


NASPInet 2.0 Architecture Guidance Paradigm Changes and Impacts

Data Bus	→	Distributed Observability Platform
PDC and gateways	→	Core-edge structure (*PDC a function not a box)*
GPS timing	→	Multi-source network timing distribution
Centralized device registry	→	Federated signals registry
PMUs at Transmission only	→	Synchronized measurement at Distribution
Minimal cyber-security	→	Integrated multi-layer security
Non-real-time / Human in the loop applications	→	Real-time / closed-loop applications
NASPInet		**NASPInet 2.0**

Architectural Validation Studies
Model Driven Co-Simulation Analysis

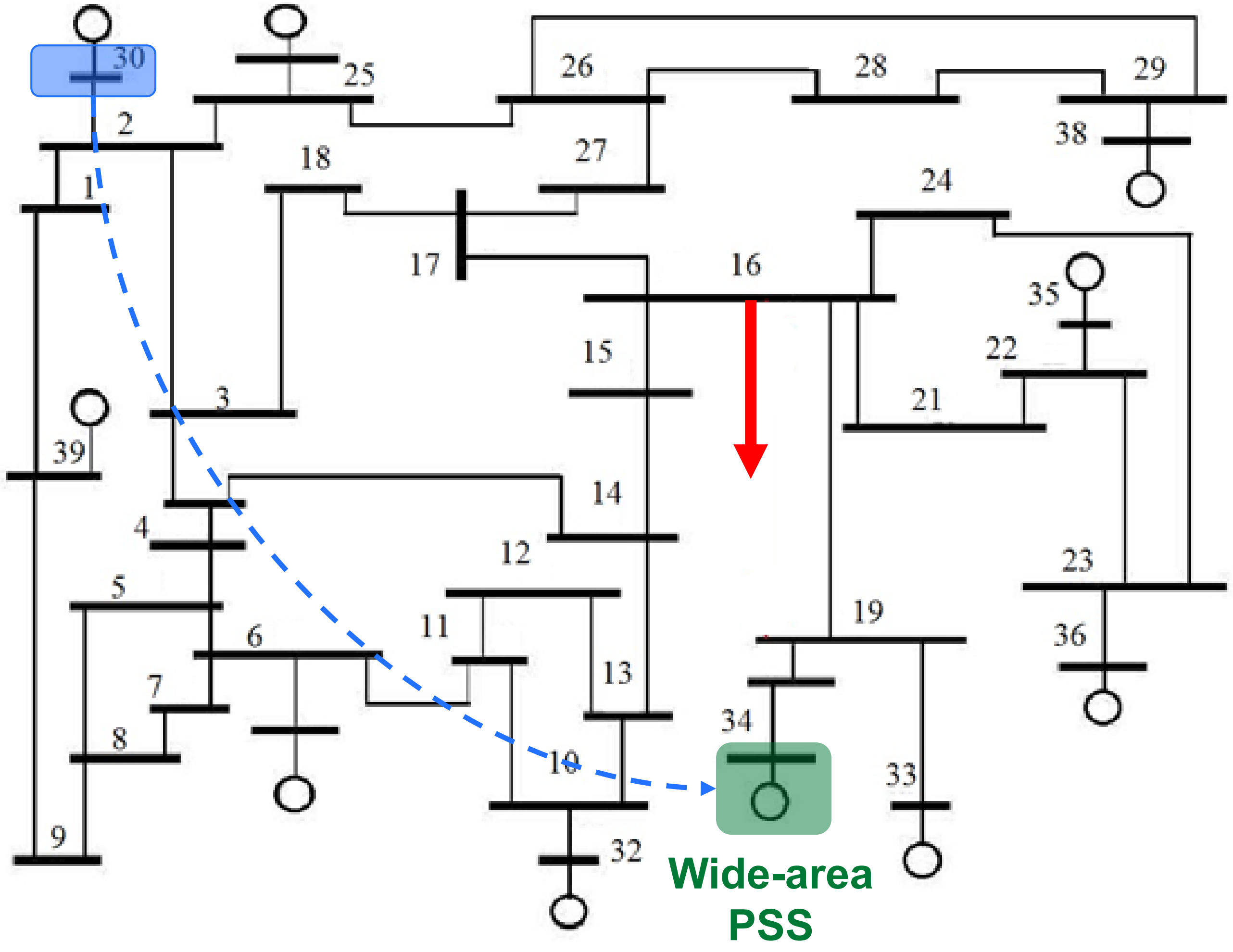
- Cyber-Physical Systems Models
  - Power system dynamics
  - PMUs, controllers, etc.
  - Telecommunications
- HELICS
  - Data exchange
  - Synchronization



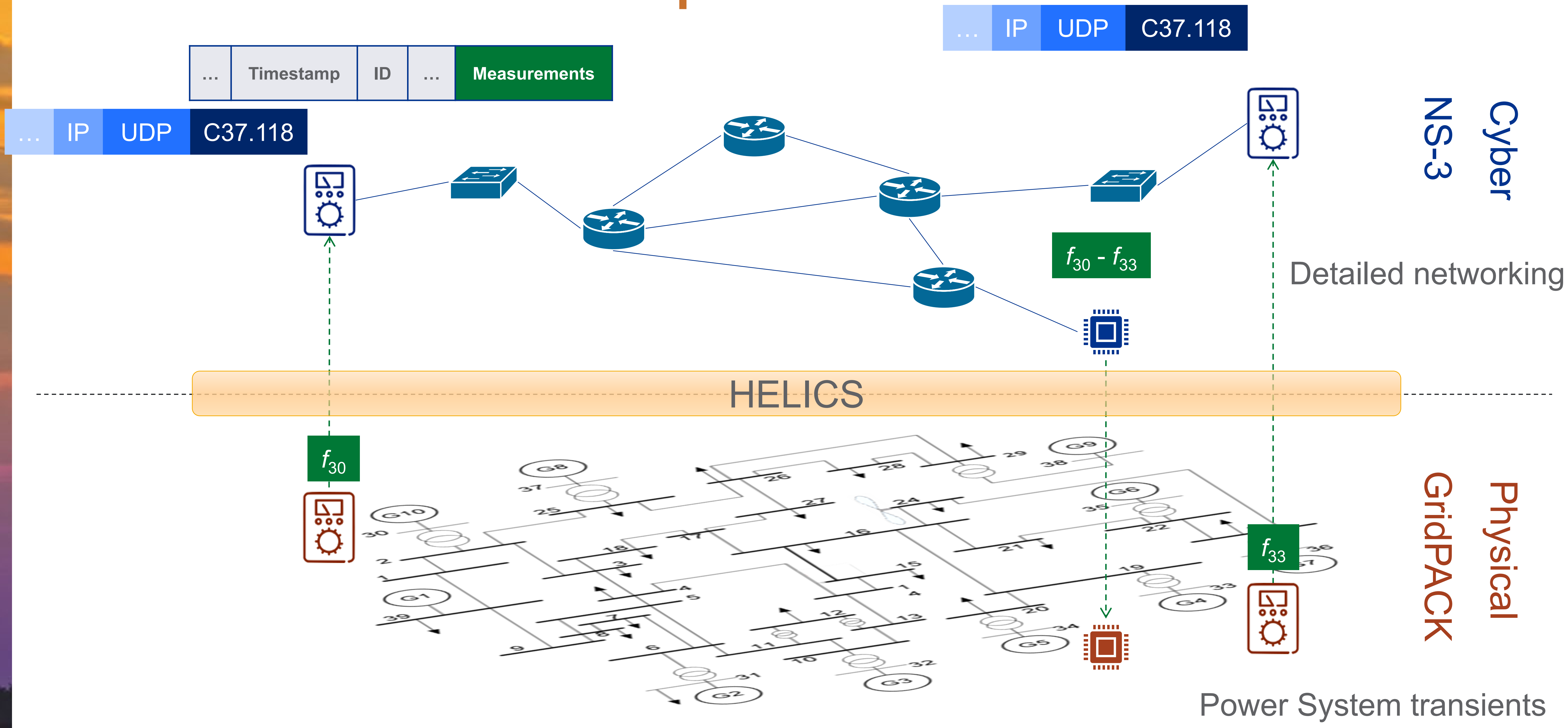
Hierarchical **E**ngine for **L**arge-scale **I**nfrastructure **C**o-**S**imulation

Wide-Area Control Use Case

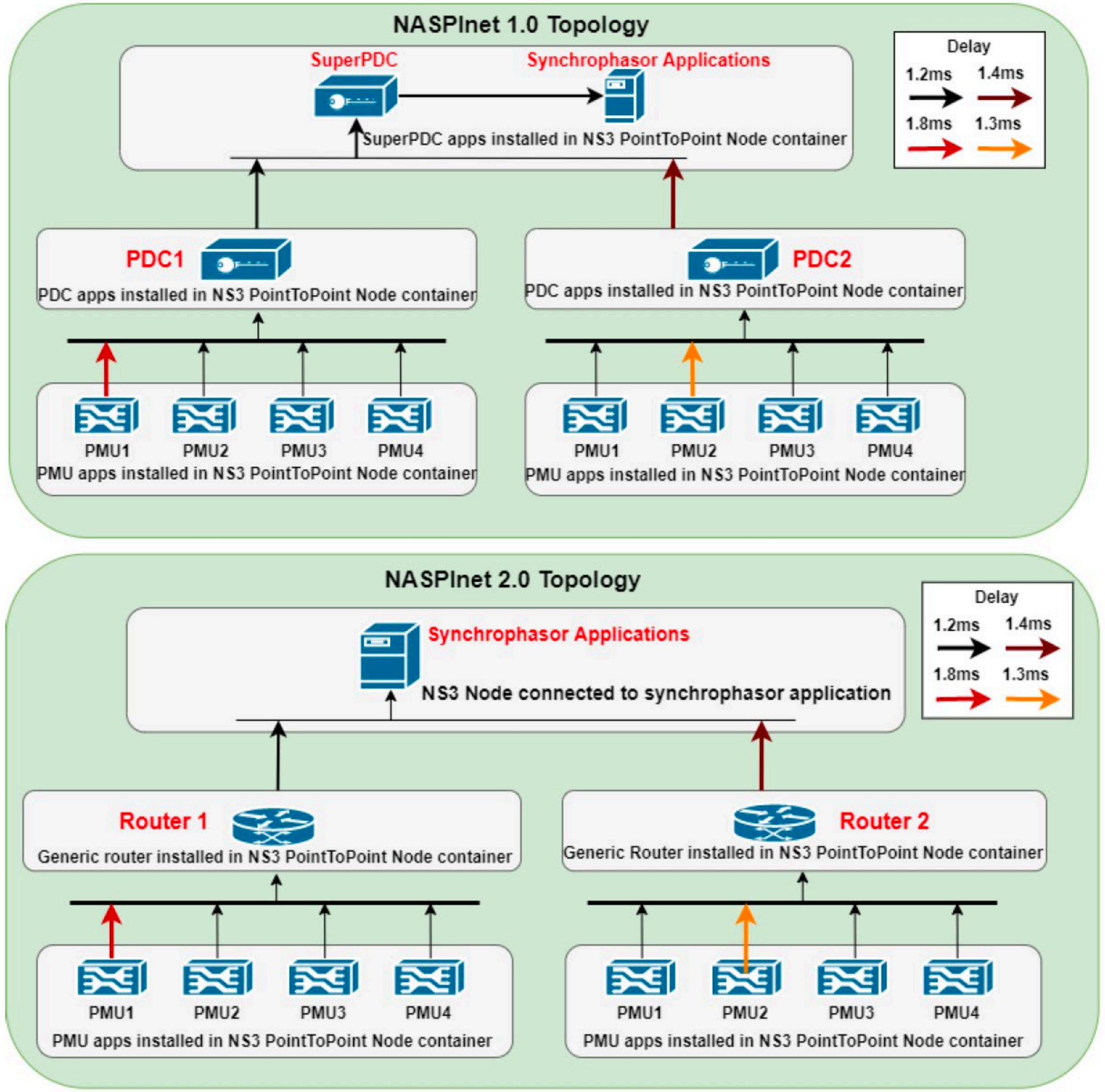
- IEEE 39-bus system
  - Wide-area PSS control at Bus 34
  - PMUs at Buses 30 and 34
- Fault at Bus 16 at `t = 1s`
- Study the impact of communication delays on system reliability



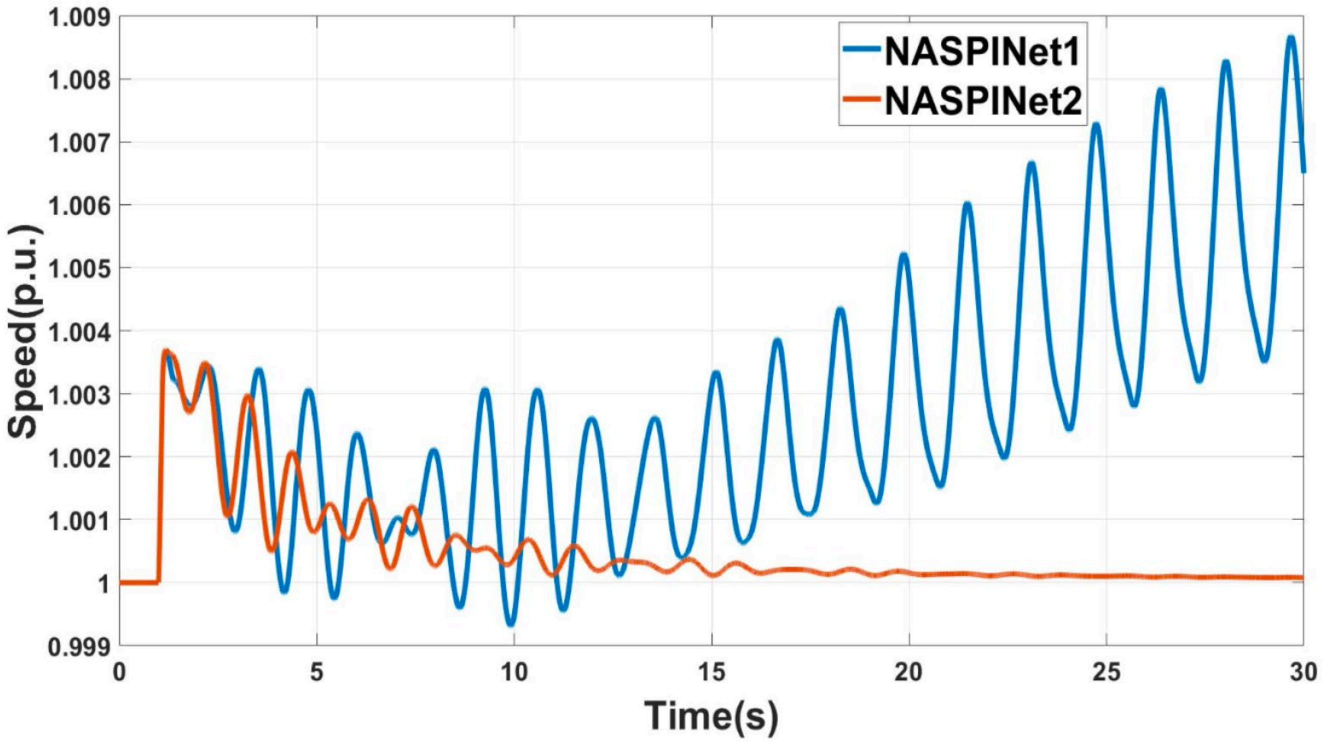
Data Flow Example



Performance Assessment

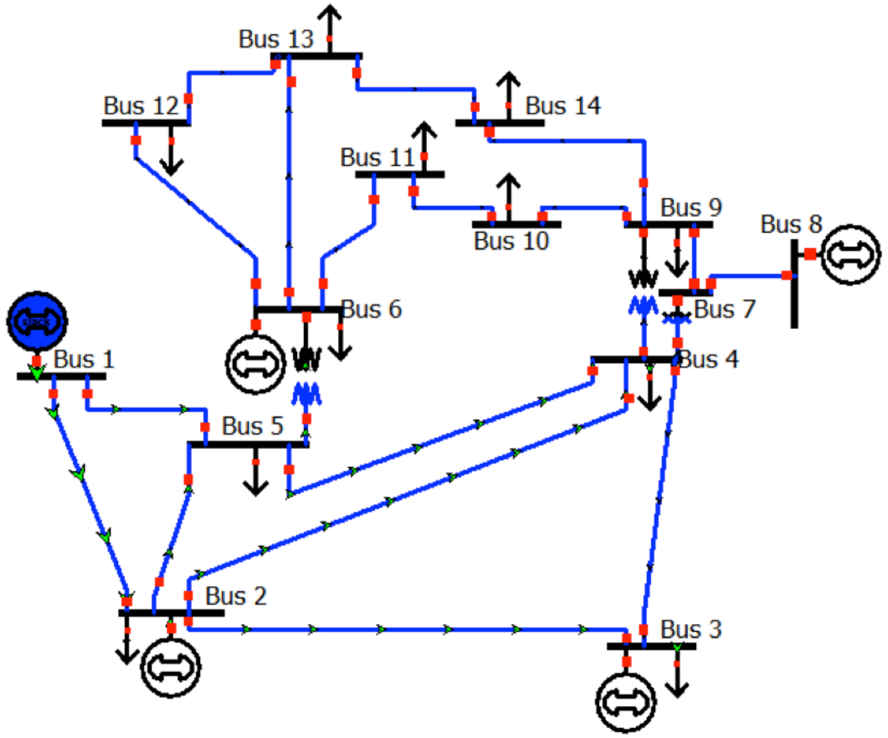


Performance of wide-area PSS with NASPInet 1.0 and 2.0



Wide-Area Protection Use Case

- Traditional protection schemes
  - Under-frequency load shedding (UFLS)
- Wide-area measurements can help protect the grid



Test System

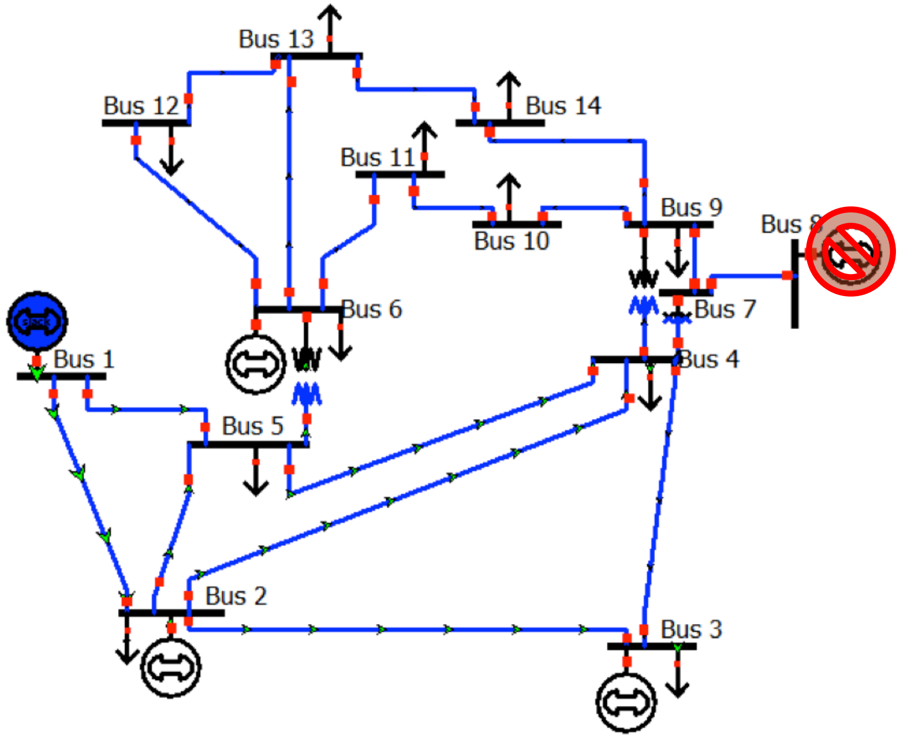
- IEEE 14-bus system
- UFLS settings

Threshold (Hz)	Time delay (cycles)*	Amount or percentage
59.5	14	10%
59.1	14	10%
58.7	14	10%

* Considering time needed to implement/actuate the decision

Case 1 - Under Frequency Load Shedding (UFLS)

- Initial Event: loss of a generator
  - Generator ID: generator at Bus 8
- Frequency drops below the threshold(s)
- UFLS happens
- Frequency rises back above the threshold
- Successful event
- Cost: unserved load



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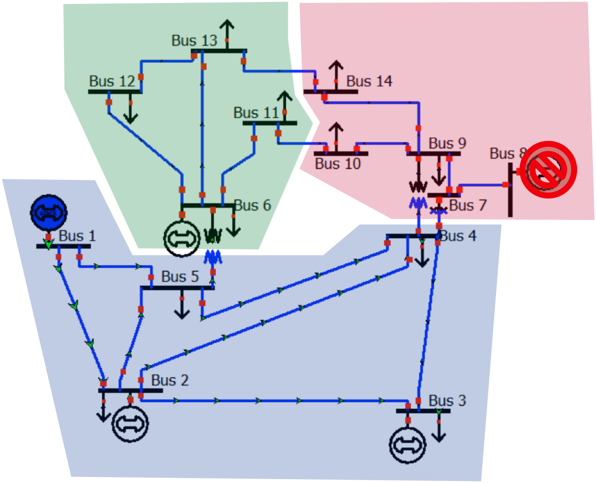
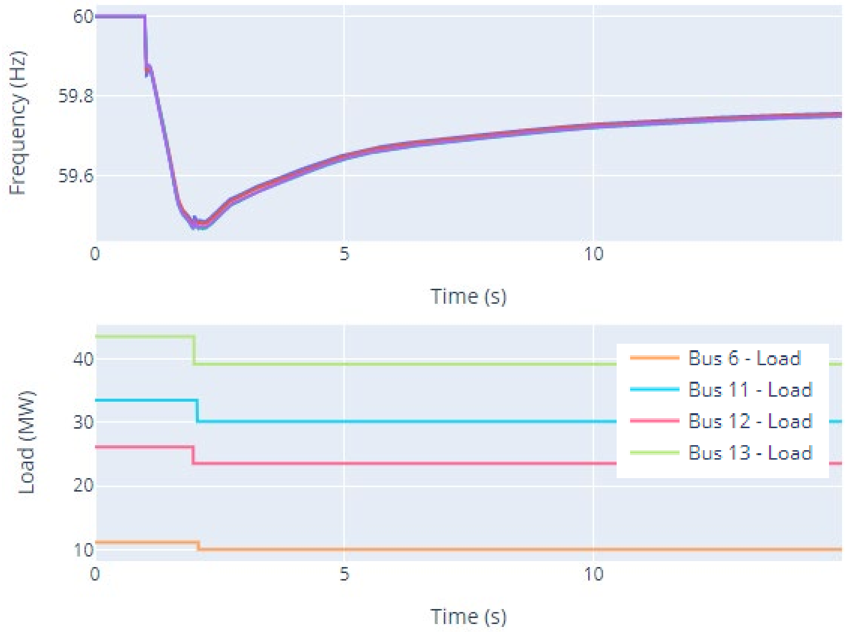
Case I: System Frequency and Load Shedding

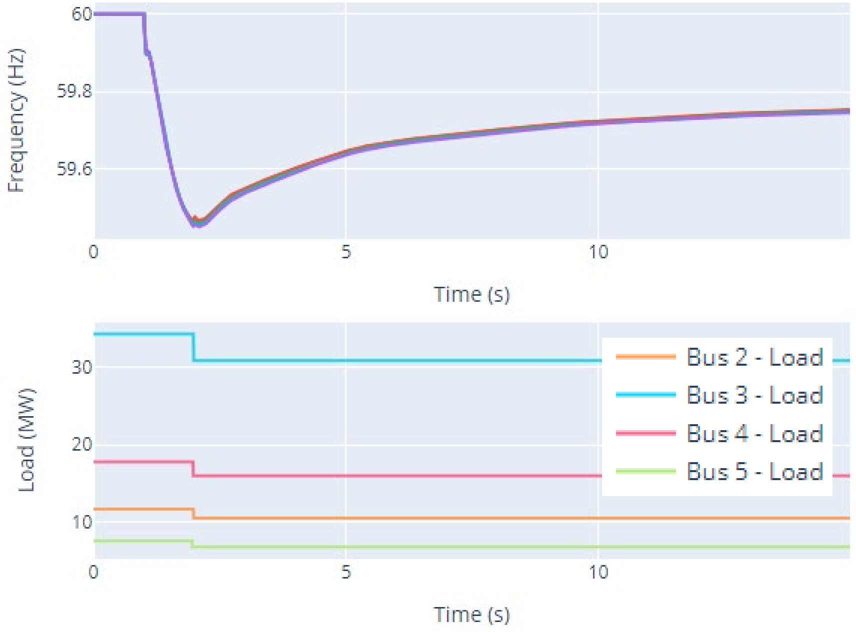
- UFLS triggered
- System remained stable
- Large amount of unserved load



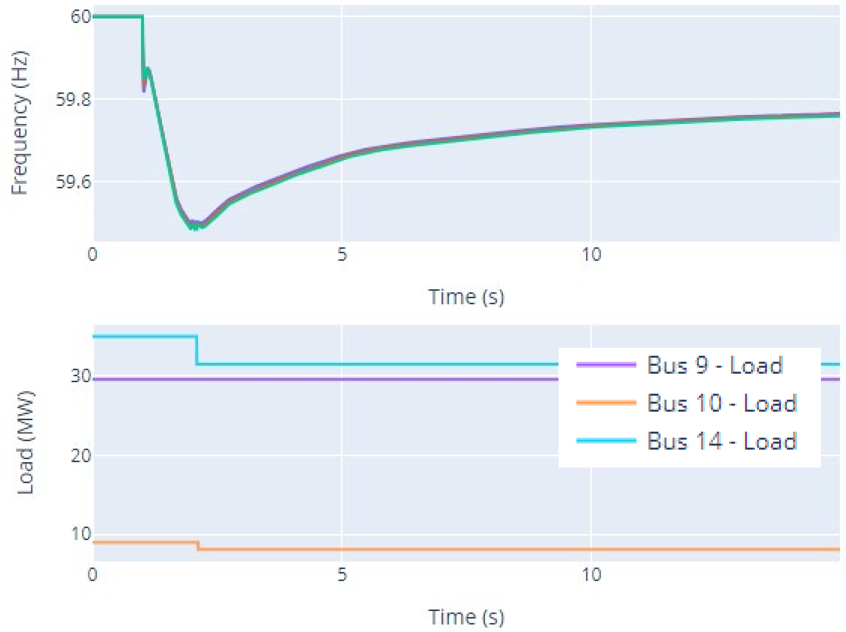
Buses 6, 11, 12, 13



Buses 2, 3, 4, 5

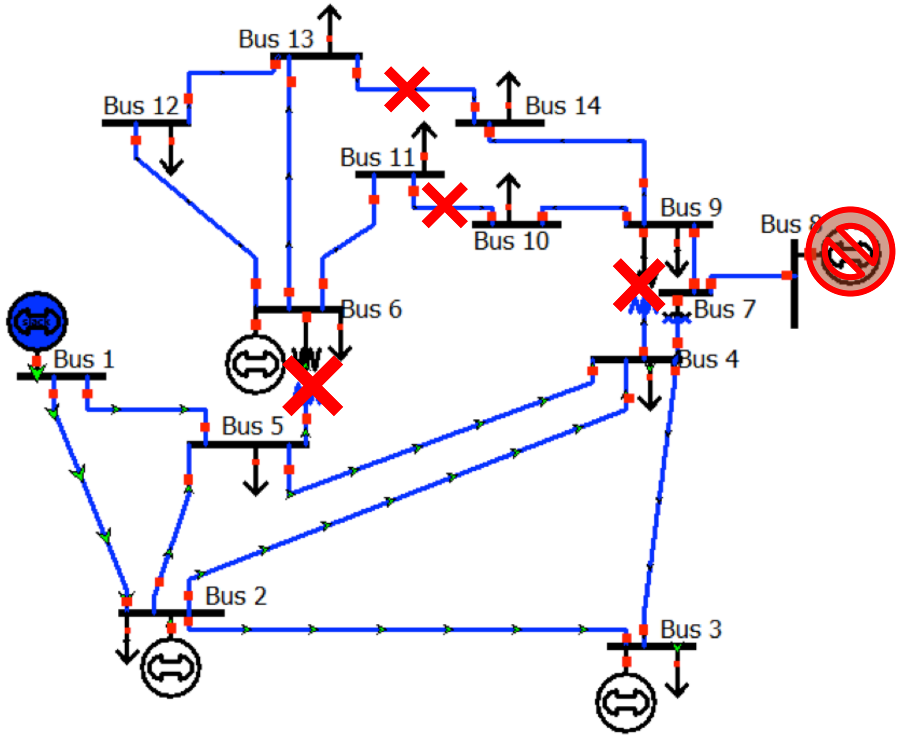


Buses 9, 10, 14



Case 2: Cascading Events

- Initial Event: loss of a generator
  - Generator ID: generator at bus 8
- Distance protection on tie line(s) triggered [1]
  - Tie line(s) tripped (cascading events)
    - ✓ Before UFLS happens
    - ✓ Lines 5-6, 4-9, 10-11, and 13-14 tripped
      - Loadability limit was reached
  - Portions of system gets islanded (or almost islanded)
- Outcome
  - Brownout or even blackout due to additional imbalance



[1] Horowitz, S.; Phadke, A. . Power System Relaying, 4th Edition, Wiley, 2014.

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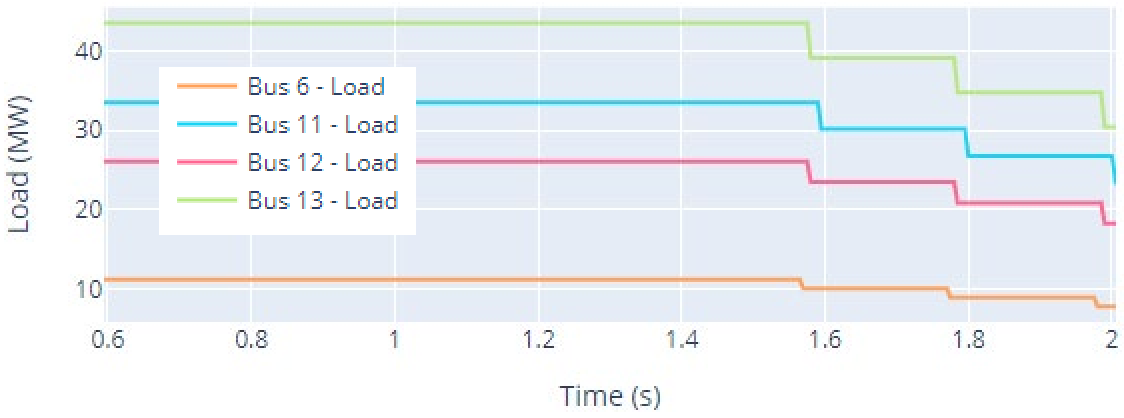
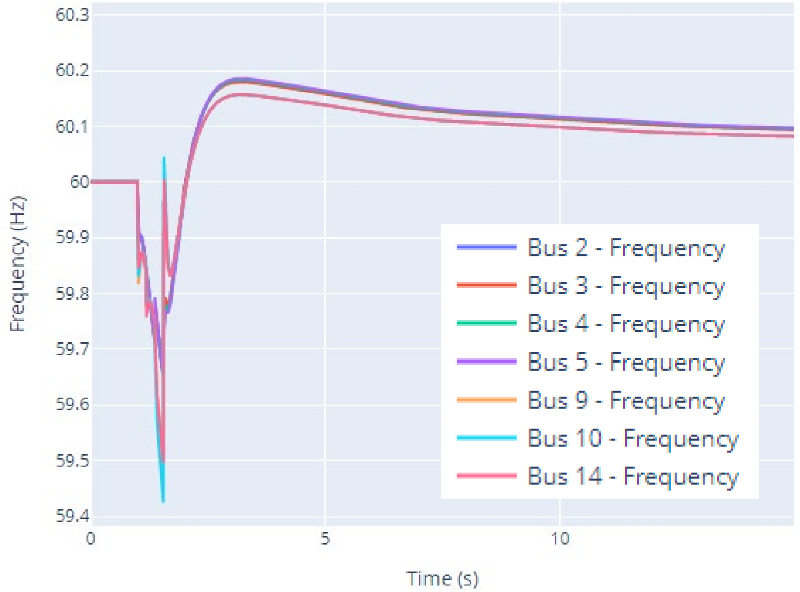
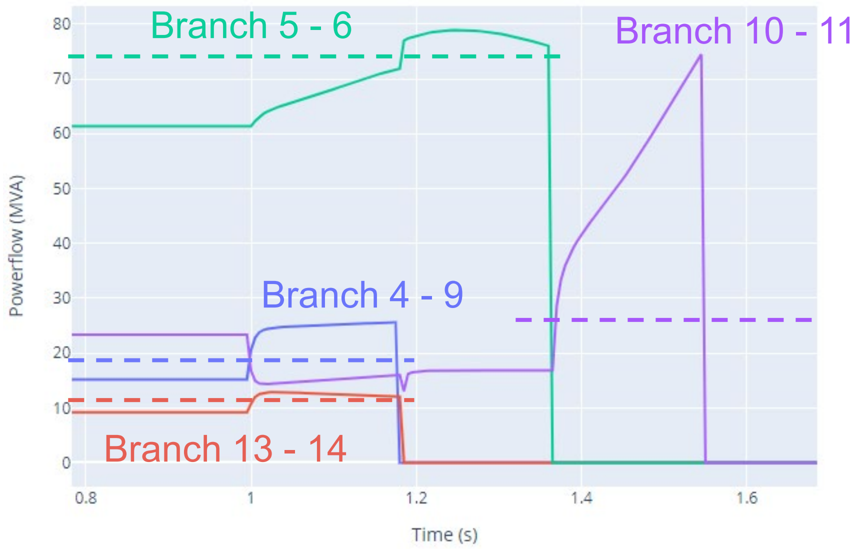
Case 2 - System Frequency and Load Shedding

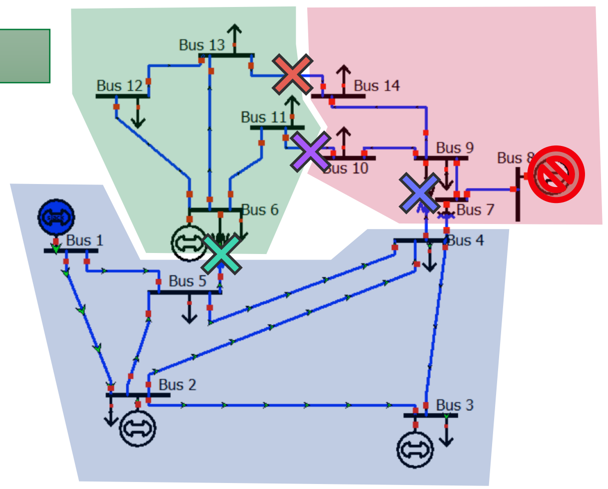
- Tie lines tripped → areas islanded → blackout or brownout

Buses 6, 11, 12, 13









Case 3: Intelligent Wide-Area Protection

- Monitoring generator buses and tie lines with PMUs, which allows
  - Fast detection of generation loss
  - Predicting power flow(s) rising over line rating(s)
- Action
  - Intelligently shed smaller amount of load than UFLS, or
  - Dispatch resources with fast ramping capability, e.g., inverter-based resources
- Possible outcomes
  - Shed smaller amount of load and/or at more appropriate locations earlier than UFLS
  - Preventing frequency from dropping below threshold
  - Avoiding a blackout or brownout

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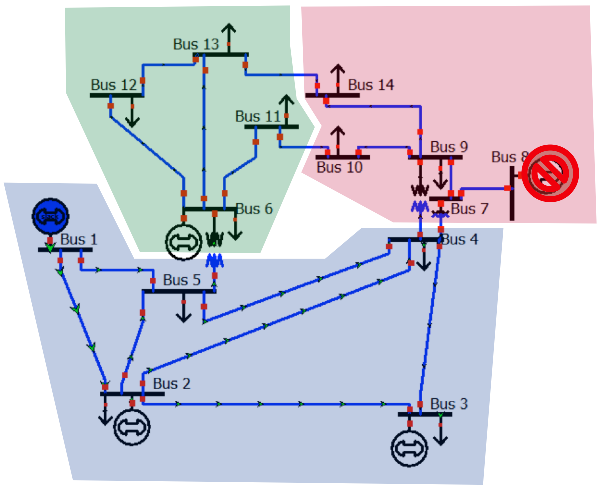
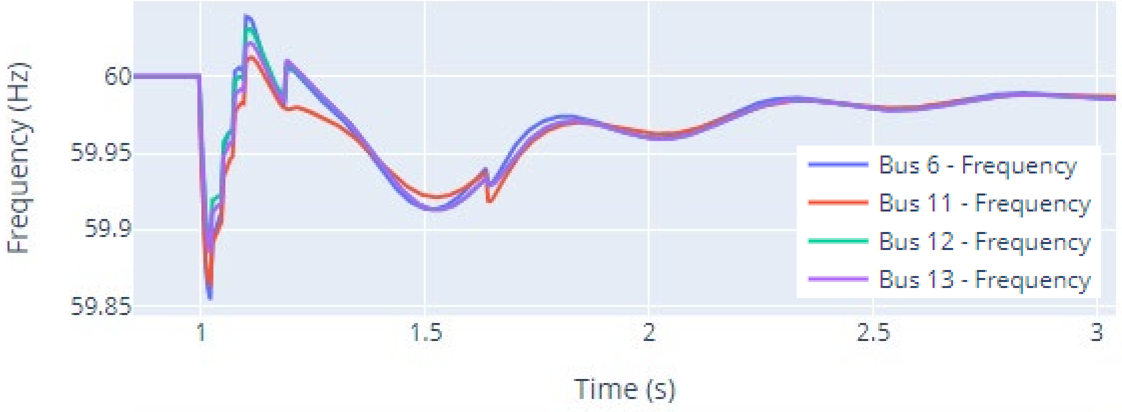
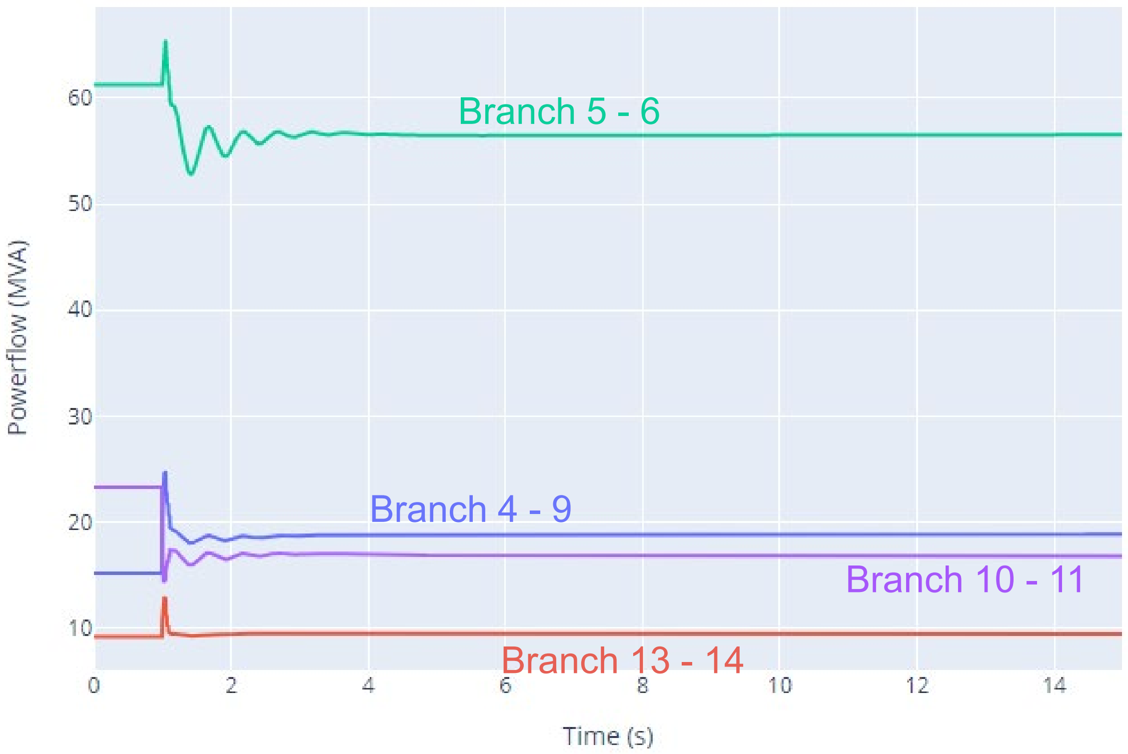
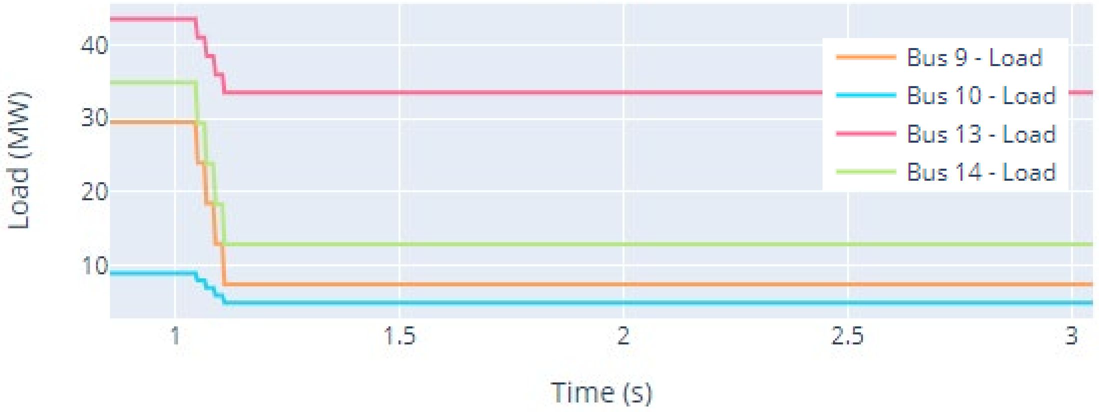
Case 3 - System Frequency and Load Shedding

- More timely and intelligent response
- System frequency recovered quickly
- Blackout avoided









Conclusions

- Wide-area PMU measurements can significantly improve system **reliability** and **resilience**
  - Better situational awareness
  - Event handling -- more **proactive**, instead of reactive
- Existing NASPInet architectures can pose severe challenges for emerging **real-time closed-loop applications**
  - PDC stacking is especially detrimental
- Great potentials, but also lots of open questions
- Planned continued work on architectural assessments and implementation strategies

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Thank you